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I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002951256 for a patent by POLY OPTICS AUSTRALIA PTY LTD as filed on 06 September 2002.

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PROVISIONAL SPECIFICATION

Invention Title: **"IMPROVEMENTS IN SIDE-SCATTERING LIGHT GUIDES"**

The invention is described in the following statement:

TITLE

IMPROVEMENTS IN SIDE-SCATTERING LIGHT GUIDES

FIELD OF THE INVENTION

The invention relates to improvements in side-scattering light guides. In particular, although not exclusively, the invention relates to side-scattering light guides that emit aesthetically pleasing sidelight when illuminated from at least one end with at least one light source.

BACKGROUND TO THE INVENTION

With reference to FIG 1, a side-scattering light guide 2 generally comprises diffuser particles 4 in a bulk material making up core 6. In general, side-scattering light guides may employ diffuser particles which individually give only a small deviation to light rays incident upon them whilst having a high transmittance, low back reflectance and low absorbance.

In particular, side-scattering light guides may utilise transparent diffuser particles that are closely refractive index matched with the core bulk material. A refractive index mismatch of a few percent is typical. Flexible polymeric side scattering light guides using these diffuser particles are the subject of the Applicant's co-pending International patent application PCT/AU02/00631.

Light escaping from such a light guide 2, represented by light ray 8, inherently tends to be emitted strongly in the forward direction. FIG 1 shows incident ray 10 initially striking light guide-air interface 12 at an angle slightly greater than the critical angle (as measured with respect to the normal to the

surface 12). At event A, total internal reflection of incident ray 10 occurs and ray 10 remains inside the light guide. At event B, ray 10 interacts with a diffuser particle and undergoes a small deviation – at most a few degrees. When the ray next strikes the guide-air interface 12 at event C, the incident angle is less than the critical angle and the ray escapes from the light guide 2. Note that a ray striking the guide-air interface 12 at the critical angle would emerge parallel to and along the light guide surface.

Ray 10 was initially travelling close to the critical angle and underwent a small deviation. Therefore, the angle at which the ray exits above the surface is also small. For example, consider a light guide of refractive index 1.50 surrounded by air. If the refractive index of the diffuser particles 4 is 1.0% higher than the bulk material of core 6, the typical angle between the exiting sidelight and the surface of the core 6 is only about 8 degrees. Increasing the refractive index mismatch to 2.0% only increases the sidelight angle to 17 degrees. Even a refractive index mismatch of 5.0% only yields a sidelight angle of 27 degrees. Surrounding the core 6 with a low refractive index jacket (rather than air) does not substantially change these angles.

Due to the close refractive index matching of the diffuser particles 4 and the core bulk material, the median deviation angle of the interactions is only a few degrees. Light will travel many light guide diameters before it exits the light guide and on any one crossing of the light guide from one side to the next, the light will usually interact with at most one diffuser particle, although it often interacts with no diffuser particles. The small deviation resulting from a single interaction or a small number of interactions means that the light ray will strike the light guide surface at an angle close to the

critical angle (it exceeded the critical angle before the interaction) and therefore will exit at a small angle to that surface. Observed from outside the light guide, light leaving the light guide appears to be strongly forward focused.

In many important applications the light guide is viewed substantially perpendicular to a longitudinal axis of the light guide, but the aforementioned type of light guides emit only a small fraction of light in a substantially perpendicular direction. They also give almost no light in the backward direction. Hence, such light guides look relatively faint when viewed from the side or from the rear.

An additional problem with such light guides is that when viewed perpendicular to the longitudinal axis of the guide, sides of the guide appear to be much brighter than the centre. The central region appears to be faintly glowing and transparent and with a slightly "milky" aspect. Many observers find this unusual appearance aesthetically unsatisfactory.

Hence, there is a need for a side-scattering light guide that addresses or at least ameliorates the aforementioned problems and emits bright, aesthetically pleasing sidelight.

DISCLOSURE OF THE INVENTION

In one form, although it need not be the only or indeed the broadest form, the invention resides in a side-scattering light guide for emission of light comprising:

a substantially transparent, substantially tubular core;

a substantially transparent or translucent coaxial core surround, said

core surround having a lower refractive index than said core; and

a supplemental diffuser element; wherein

said core includes a light scattering additive arranged to scatter light within said core so that at least some of said light passes through a side of said core.

Suitably, the supplemental diffuser element is a rough outer surface of said core.

Suitably, the supplemental diffuser element is a rough outer surface of said core produced by a sufficiently high concentration of said light scattering additive.

Suitably, the supplemental diffuser element may be an opaque diffusely reflecting coaxial jacket covering at least part of said substantially tubular core.

Suitably, the supplemental diffuser element may be transparent or translucent and in the form of a coaxial jacket that surrounds said substantially tubular core.

Suitably, the supplemental diffuser element may be an opaque absorbing coaxial jacket surrounding the substantially tubular core, said opaque absorbing coaxial jacket comprising at least one aperture.

Suitably, a transparent or translucent coaxial diffuser jacket may be disposed between the core and the opaque absorbing coaxial jacket.

Suitably, a transparent or translucent coaxial diffuser jacket may cover at least one aperture in the opaque absorbing coaxial jacket.

Suitably, the supplemental diffuser element may be an opaque diffusely reflecting coaxial jacket surrounding the substantially tubular core,

said opaque diffusely reflecting coaxial jacket comprising at least one aperture.

Suitably, a transparent or translucent coaxial diffuser jacket may be disposed between the core and the opaque diffusely reflecting coaxial jacket.

Suitably, a transparent or translucent coaxial diffuser jacket may cover at least one of the apertures in the opaque diffusely reflecting coaxial jacket.

Suitably, the opaque diffusely reflecting coaxial jacket comprises at least one discrete aperture or a longitudinal slit.

Preferably, said opaque diffusing coaxial jacket comprises an at least partially reflective surface facing said core.

Suitably, the light guide is rigid. Alternatively the light guide may be flexible.

The core is preferably a polymer, such as acrylic. Alternatively, the core may be glass.

The light scattering additive is preferably transparent.

The light scattering additive is preferably made from a polymer and may be a cross-linked polymer, such as PMMA or polystyrene. Alternatively the light scattering additive may be made from transparent non-polymeric materials such as glass.

The light scattering additive preferably comprises diffuser particles. The diffuser particles are preferably spherical. Alternatively, the diffuser particles may be cylindrical, polyhedral, ellipsoidal or asymmetrical in shape.

Preferably, the light scattering additive yields a high ratio of angular

deviation to back reflection of the light.

The light scattering additive is preferably selected to have a refractive index close to a refractive index of the core.

In one embodiment, said light guide comprises an axial diffuser particle number (the average number of diffuser particles a ray parallel to a longitudinal axis of the light guide would intercept if it were to pass through the guide undeviated) in the range of about 10 – 50.

In another embodiment, said light guide comprises an axial diffuser particle number in the range of about 50 – 300.

In a further embodiment, said light guide comprises a linear diffuser particle number of the order of 10^3 diffuser particles per metre.

Further forms of the invention will become apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

To assist in understanding the invention and to enable a person skilled in the art to put the invention into practical effect preferred embodiments of the invention will be described by way of example only with reference to the accompanying drawings, wherein:

FIG 1 shows a prior art side-scattering light guide;

FIG 2 shows a side-scattering light guide in accordance with a first embodiment of the invention;

FIG 3 shows a side-scattering light guide in accordance with a second embodiment of the invention;

FIG 4 shows a perspective view of the side-scattering light guide of FIG 3;

FIG 5 shows a side-scattering light guide in accordance with a third embodiment of the invention;

FIG 6 shows a side-scattering light guide in accordance with a fourth embodiment of the invention;

FIG 7 illustrates an application of the light guide of FIG 6;

FIG 8 shows a side-scattering light guide in accordance with a fifth embodiment of the invention;

FIG 9 illustrates an application of the light guide of FIG 8;

FIG 10 shows an end view of the application shown in FIG 9; and

FIG 11 shows a side-scattering light guide in accordance with a sixth embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The light guide 2 of the present invention comprises a substantially tubular polymer core 6 formed from a bulk medium in the form of a polymer matrix, which is impregnated with a light scattering additive in the form of diffuser particles 4. In one embodiment the polymer matrix is formed of Poly-methyl methacrylate (PMMA). The diffuser particles 4 may be formed of a cross-linked polymer, which is capable of being added to heated PMMA without the diffuser particles 4 dissolving or significantly deforming.

In an alternative embodiment, the diffuser particles 4 are formed of cross-linked PMMA particles embedded within a polymer matrix made from a polymerised acrylate mixture consisting primarily of methyl methacrylate

(MMA) and allyl diglycol carbonate (CR39). Alternatively, BMA (butyl methacrylate) may be substituted for MMA.

In another embodiment, the polymer core 6 is formed, for example, by extrusion or injection moulding from a bulk medium in the form of a polymer matrix, which is impregnated with the light scattering additive in the form of diffuser particles 4. In another embodiment, the diffuser particles may be made from polystyrene.

In yet another embodiment, the core 6 is formed of glass by extrusion or moulding from a bulk medium in the form of a glass matrix, which is impregnated with the light scattering additive in the form of diffuser particles 4. The diffuser particles are of a form that can resist the high temperature of the molten glass. Silica is known to be a suitable material for such diffuser particles 4.

Methods of manufacturing side-scattering light guides comprising light scattering additives in the form of diffuser particles are disclosed in the Applicant's co-pending International patent application PCT/AU02/00631, the contents of which is hereby incorporated by reference.

According to a first embodiment of the invention and with reference to FIG 2, light emitted from a side-scattering light guide of the type described above may be made more uniform in intensity and more aesthetically pleasing by surrounding the core 6 with a diffuser element in the form of a translucent coaxial diffuser jacket 14. This jacket may be made from translucent polyethylene, translucent teflon, translucent ABS, translucent PVC, translucent glass, or other translucent materials that have reasonably high tansmittance and low absorbance. Referring to event D, light scattered

by diffuser particle 4 and escaping the core 6 is diffused by the translucent diffuser jacket 14. The translucent diffuser jacket should have the lowest possible absorption to minimise the loss of light.

With reference to event E, any light reflected by one diffuser surface is likely to pass through the essentially transparent light guide core 6 to the other side of the diffuser jacket where it can potentially escape the core 6 and jacket 14, as represented by event F in FIG 2. Thus, while a high degree of reflectivity in the diffuser is not ordinarily desirable, it may be acceptable provided the absorption is low.

In FIG 2, an air layer 16 surrounds the core 6, but replacing the air layer with a low refractive index jacket does not substantially change the results.

When viewed from a distance substantially perpendicular to the longitudinal axis of the light guide, the external diffuser surface has a pleasing, bright, substantially uniform appearance that is greatly superior to that of the bare, prior art side-scattering light guide in most applications.

According to a second embodiment of the invention and with reference to FIGS 3 and 4, the appearance of light emitted from a side-scattering light guide is improved by placing the core 6 adjacent an opaque diffusely reflecting diffuser 18. Light exiting the core 6 in a direction of the opaque reflective diffuser 18 is not transmitted through the diffuser, but is diffused at a wide range of angles, as represented by event G in FIG 3. This light may be viewed directly or through the essentially transparent light guide 2. The side-scattered light has a pleasing, bright, substantially uniform appearance.

In a preferred second embodiment of the invention, the light guide 2 is half surrounded by a white opaque diffuser 18 as shown in FIG 4.

Note that light escaping the light guide 2 on the side away from the opaque diffuser 18 will be forward focused. Accordingly, in many applications it may be desirable to simultaneously use a transparent coaxial diffuser 14 as described in the first embodiment and part surrounding opaque diffuser 18 as described in the second embodiment to produce superior quality light than either alone would produce with the light guide.

Note that in the second embodiment, the core 6 is surrounded by air. However, surrounding the core 6 with a low refractive index jacket does not substantially change the results.

For some applications it is required that the light be emitted from a number of discrete locations along the side-scattering light guide rather than as a continuous linear source. According to a third embodiment of the present invention and with reference to FIG 5, one way of achieving this is to surround the core 6 with an opaque absorbing coaxial jacket 20 that has an aperture 22 at locations along the jacket at which it is desired that light is emitted.

However, light exiting the apertures 22, as shown at event H will be strongly forward focused. Also, the apertures make up only a small fraction of the jacket surface area allowing only a small fraction of the light escaping the core 6 to escape through the apertures 22. As shown at event J, the jacket 20 will absorb the majority of the light emitted from the side of the core 6. This loss factor is typically more than 95% and may exceed 99%. Thus the apertures 22 viewed substantially perpendicular to the longitudinal axis

of the guide, which is the typical viewing direction, particularly for such an application, will look faint. Furthermore, the small amount of light emitted through the apertures is focused at angles approaching 90 degrees to the viewing direction.

With a transparent or translucent coaxial diffuser jacket surrounding the core 6 and the opaque absorbing coaxial jacket 20 surrounding the transparent coaxial diffuser jacket, the light exiting the apertures 22 is more uniform in angular distribution. Hence, when the light guide is viewed side on as intended, the brightness of the emitted light is greater than when the transparent coaxial diffuser jacket is omitted. However, this combination does not increase the quantity of light.

In accordance with a fourth embodiment of the invention and with reference to FIG 6, the inventors have identified that by surrounding the core 6 with an opaque diffusely reflecting coaxial diffuser jacket 24 the brightness of the emitted light is much greater than produced in the previous two embodiments.

Conventionally, light escaping from the light guide 2 is strongly forward focused. Once it reflects off a wall of the opaque coaxial diffuser jacket 24, as represented by event K, it takes on a substantially uniform angular spread. The essentially transparent core 6 will allow this now diffuse light to bounce around inside the system until it either: (i) escapes through an aperture 22 in the diffuser jacket wall (the desired alternative); (ii) is absorbed in the diffuser jacket wall 24 or in the core 6; or (iii) is scattered by a diffuser particle 4 in the core 6 in a way that leads to its recapture by that

light guide. Alternative (iii) simply returns the light to its previous condition and does not lead to any loss.

The only loss mechanism is absorption by the opaque diffusely reflecting diffuser jacket 24 or the core 6. However, the core 6 has very low absorption. Therefore, if the diffuser walls also have low absorption and high reflectance, light can undergo many interactions with the walls before it is absorbed. If light reaches an aperture 22 before it is absorbed then it will escape through that aperture. Consequently, with a highly reflective diffuser it is possible to direct a substantial fraction of the light escaping from the guide 2 into the apertures. For a perfectly reflecting diffuser it is theoretically possible to couple nearly all of the light leaving the light guide 2 with the apertures by virtue of the mechanisms described above. This compares to a coupling efficiency of at best a few percent for absorbing coaxial jackets.

Note that the more important factor for increased output is the reflectivity of the diffuser rather than its degree of diffusion. In the limit, a "diffuser" having a purely specular reflecting surface (i.e. a perfect mirror with no diffusing properties at all) would lead to increased output, although the exiting light would be strongly forward focused. The fact that the light undergoes many reflections off the diffuser surfaces means that even a low degree of diffusion at each interaction will lead to a relatively uniform angle distribution for the light exiting the apertures.

Viewed externally, the apertures emit bright light having a pleasing, substantially uniform appearance.

A variation on the fourth embodiment is to surround one or more of the apertures of the diffusely reflecting coaxial jacket 24 with a transparent

or translucent coaxial diffuser jacket to further diffuse the light emitted through the apertures.

With reference to FIG 7, the high surface brightness at the apertures means that they can usefully serve as auxiliary light sources for optical elements that focus and direct the light in preferred directions. FIG 7 illustrates the use of refractive optical elements in the form of lenses 26 for this purpose, but reflective optics, dispersive elements or combinations thereof are also suitable.

In accordance with a fifth embodiment of the invention and with reference to FIG 8, the opaque diffuser jacket 24 comprises a narrow, longitudinal slit 28. The slit can serve as a narrow auxiliary linear light source, for example, for optical elements that focus and direct the light in preferred directions. That linear light source may be focused with essentially cylindrical optics, as shown in FIGS 9 and 10. FIGS 9 and 10 illustrate the use of refractive optics in the form of a cylindrical lens 30 for this purpose, but reflective optics, dispersive elements or combinations thereof are also suitable.

A useful application of the auxiliary linear light source of the fifth embodiment of the invention is as a linear light source for edge-lit signs, displays and the like.

Note that in FIGS 5 to 10, the core 6 is surrounded by air. However, surrounding the core 6 with a low refractive index jacket does not substantially change the results.

According to another embodiment of the invention, the concentration of diffuser particles 4 in the core 6 is selected to be of the order of 10^3

particles per metre. The inventors have identified that with such a high concentration of diffuser particles in the polymer matrix, the core 6 produced through, for example, an extrusion process, comprises a rough outer surface 32, as shown in FIG 11. The roughness in the outer surface is produced by the diffuser particles 4, the high concentration of which modifies surface tension effects that would ordinarily keep much lower concentrations of diffuser particles in the interior of the core, thus producing a smooth surface.

In one example according to this embodiment of the invention, a PMMA rod was doped with diffuser particles at a linear diffuser particle frequency of approximately 1650 particles per metre. The rod was surrounded by air that served as the low refractive index component of the light guide. The refractive index difference between the polymer matrix and the diffuser particles was approximately 1.1%. The rough surface of the light guide acts as a supplemental diffuser element producing bright light having a pleasing, substantially uniform appearance.

The rough surface is achieved in the core production process, e.g. by extrusion, and obviates the prior art need for a smooth outer surface of the core to undergo further treatment in order to produce a rough diffusing surface.

However, the rough outer surface of the core 6 may alternatively be produced by adding a small amount of water to the extrusion material, roughening the edge of the extrusion dye, or any of the methods commonly used to extrude rough surfaces. As another alternative, the surface of the core 6 may be roughened by abrasion or by the use of solvents. As a further alternative, if the core is produced by injection moulding, the rough surface

may be produced by utilising a suitable surface on the mould. These methods may be used as an alternative or in addition to method in the embodiment described above employing high concentrations of diffuser particles.

Throughout the specification the aim has been to describe the invention without limiting the invention to any one embodiment or specific collection of features. Persons skilled in the relevant art may realize variations from the specific embodiments that will nonetheless fall within the scope of the invention.

Dated this Sixth day of September 2002

POLYOPTICS AUSTRALIA PTY LTD

By their Patent Attorneys

FISHER ADAMS KELLY

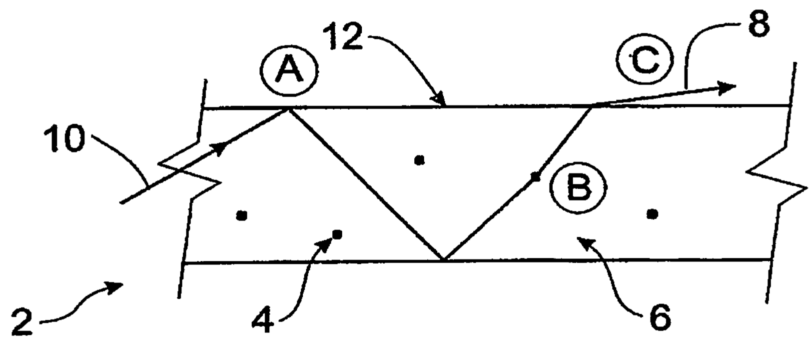


FIG. 1

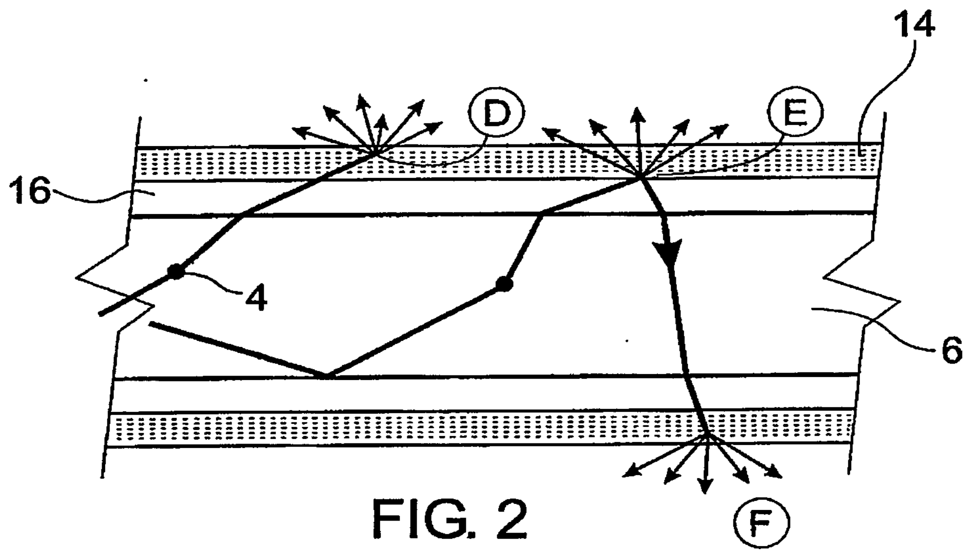


FIG. 2

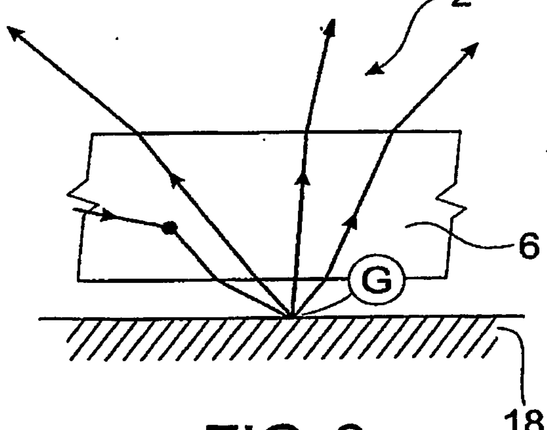


FIG. 3

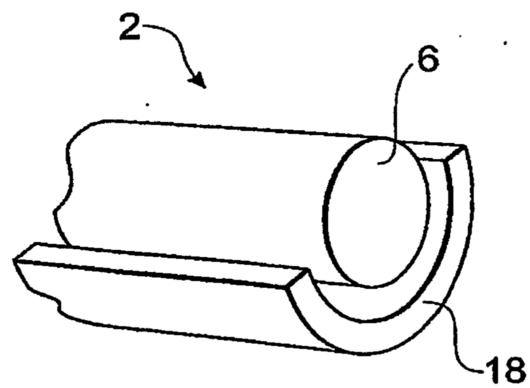


FIG. 4

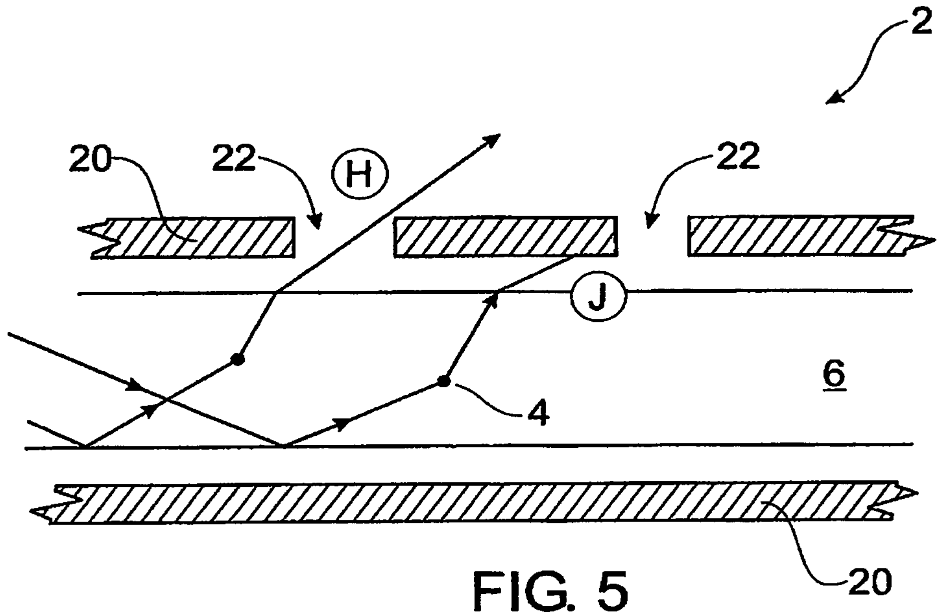


FIG. 5

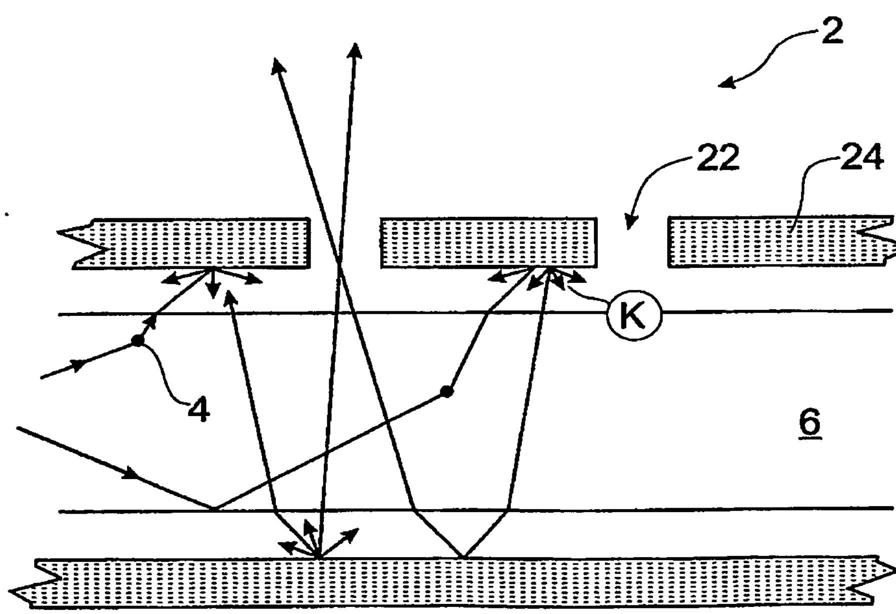


FIG. 6

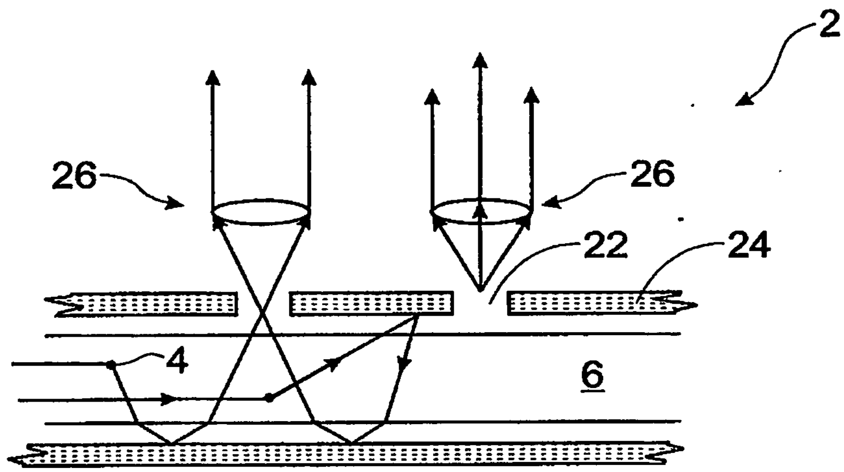
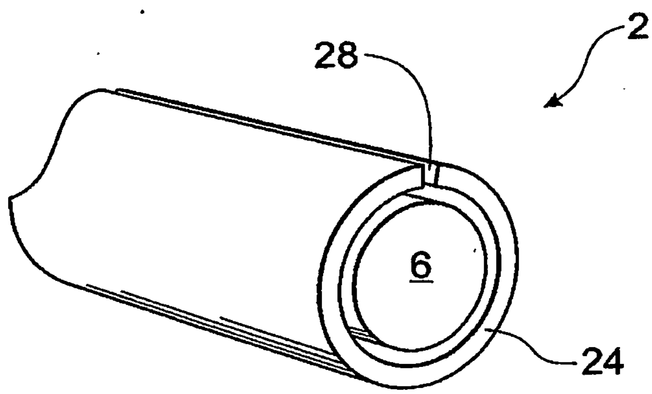


FIG. 7

FIG. 8



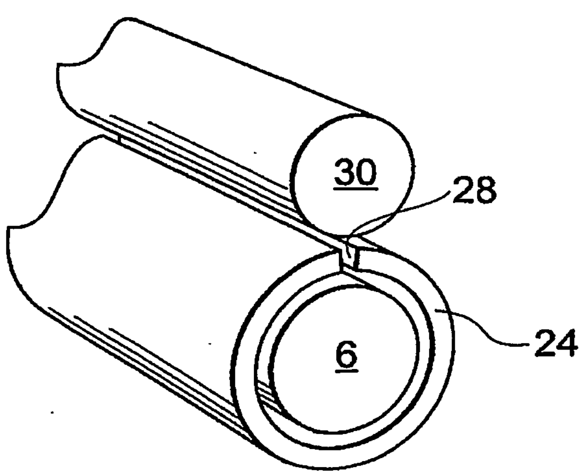


FIG. 9

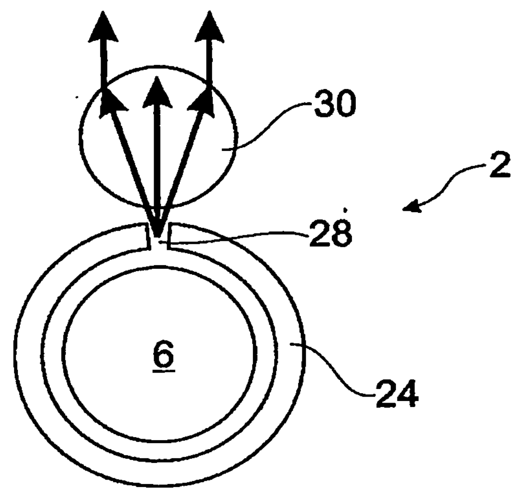


FIG. 10

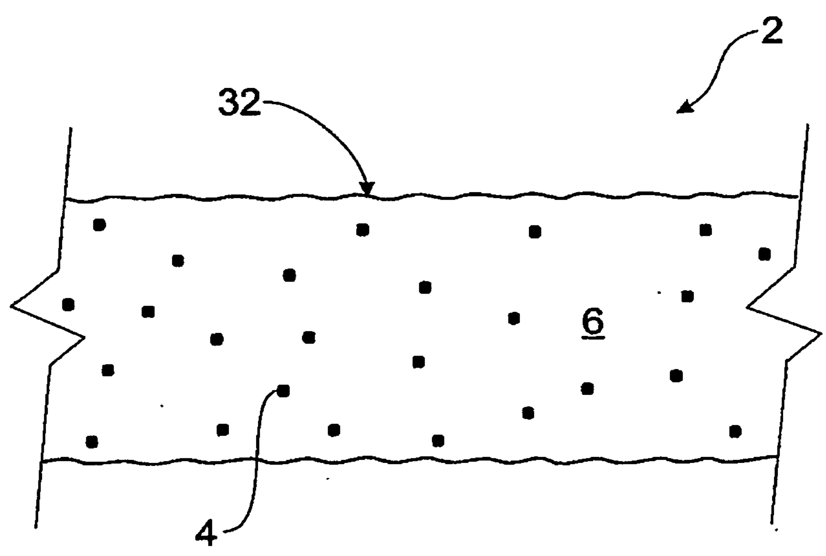


FIG. 11